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DESIGN AND DEVELOPMENT OF PRESSURE AND REPRESSURIZATION PURGE SYSTEM FOR REUSABLE SPACE SHUTTLE MULTILAYER INSULATION SYSTEMS

PHASE REPORT

GENERAL DYNAMICS
Convair Aerospace Division

DESIGN AND DEVELOPMENT OF PRESSURE AND REPRESSURIZATION PURGE SYSTEM FOR REUSABLE SPACE SHUTTLE MULTILAYER INSULATION SYSTEM

632-3-286

Progress Report for Manufacturing Phase of Program

Contract NAS8-27419

Prepared for
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SUMMARY

This report covers the work performed under the manufacturing phase of NASA/MSFC Contract NAS8-27419, Design and Development of Pressure and Repressurization Purge System for Reusable Space Shuttle Multilayer Insulation System, by Convair Aerospace Division of General Dynamics, San Diego, California. The accomplishments of the phase are summarized below.

The manufacturing tasks for the program included the fabrication and assembly of an epoxy fiberglass purge bag to encapsulate an insulated cryogenic propellant tank. Purge, repressurization and venting hardware were procured and installed on the purge bag assembly in preparation for performance testing. The fabrication and installation of the Superfloc multilayer insulation (MLI) on the cryogenic tank was accomplished as part of a continuing Convair IRAD program. An abstraction of the results of the MLI fabrication task is included to describe the complete fabrication requirements for a reusable cryogenic propellant space storage system.

A completely reusable MLI system using Superfloc was developed and built to conform to space shuttle life and environmental requirements. The major system requirements which served as design drivers for the reusable MLI system were:

system service life	10 years and 100 missions
mission duration	30 days
pretanking purge (GN_2)	381 ± 14K (225 ± 25F)
MLI vent down pressure	10^{-4} Torr within 1 hour
temperature environment	200 to 450K (-100 to 350F)
moisture environment	no condensable gases

Goldized Kapton (a polyimide) was selected as the reflective shield material to meet the reusable MLI requirements due to its ability to withstand reentry temperatures and repeated moisture exposure. Polyphenylene Oxide (PPO) was selected to serve as the MLI blanket fastener material due to its relatively high strength at elevated temperatures (to 450K).

The Superfloc manufacturing techniques were significantly improved over those used to produce the material for previous applications. A new silk screening process was developed for applying the dacron flocking dots on the reflective shields which significantly reduced the time necessary for producing Superfloc. In addition the manufacturing scrap was reduced to essentially zero. A continuous printing technique was also developed for the silk screening operation which replaced the "step and repeat" process used on previous research programs.

A new load carrying face sheet was developed for the Superfloc MLI blankets. The sheet is made from Pyre M-L (a polyimide) resin reinforced with beta glass cloth. The materials were again selected to withstand the high temperature associated with space shuttle reentry conditions. A one piece aluminum male mold in the form of a curved gore was used as a base to form the face sheets. Mylar sheeting served as release agent on the mold for the painted coat of Pyre M-L resin and imbedded beta glass. The face sheet was oven cured to provide a preformed face sheet of sufficient strength to carry all insulation blanket flight imposed loads.

MLI blankets for the 2.21 meter diameter LH_2 test tank were fabricated on the same tooling as was used previously (1969) for an expendable aluminized mylar MLI system tested on the same tank. Blankets were "laid-up" on the gore shaped tooling using polyeurathane foam spacers intermittently to provide the proper blanket layer density control (30 layers per inch) prior to blanket trim operations. Each of the twenty-four 0.524 radian (30°) gore blankets and the 4 flat end cap blankets contained twenty-two gold Kapton reflective shields. PPO grommets, pins and links were used for blanket support, attachment and layer density control when the blankets were removed from the assembly tools.

Blanket installation on the LH_2 test tank was accomplished in two separate blanket layers. Each blanket layer consisted of twelve curved gore sections and two circular flat end cap sections. The gore blanket longitudinal butt joint seams were offset by one inch to preclude a straight through joint susceptible to radiation tunnelling directly to the tank. Assembly of the gore sections to the tank was facilitated by making the final gore in each of the blanket layers a cut-to-fit part. The blankets were hung from the tank by the use of fiberglass support pins; PPO slotted purge pins were also installed in the blankets for use with the helium purge gas distribution system.

The reusable MLI system as designed, fabricated and installed on the 87-inch diameter test tank represented not only an advancement in MLI reusability capability, but an advancement in thermal performance capability. The system is presently ready for thermal and structural evaluation. The predicted ρK product for the new system is 1.65 mW-Kg/m^4-K at temperatures between 291K and 22.2K.

The purge bag used with the MLI purge and repressurization subsystem is designed to provide an enclosure around the MLI during ground purging with gaseous helium; to provide a receptacle for MLI repressurization gas during atmospheric reentry; to provide a protective enclosure for the MLI during repeated flight and maintenance cycles; and to provide a closed container for inerting gas (helium) during vehicle storage periods. The configuration of the MLI purge and repressurization system is shown in Figure S-1. The purge bag is made of three sections; two thin wall bag sections and a reinforced penetration panel which supports the fluid loop hardware for the purge, vent and repressurization subsystems.

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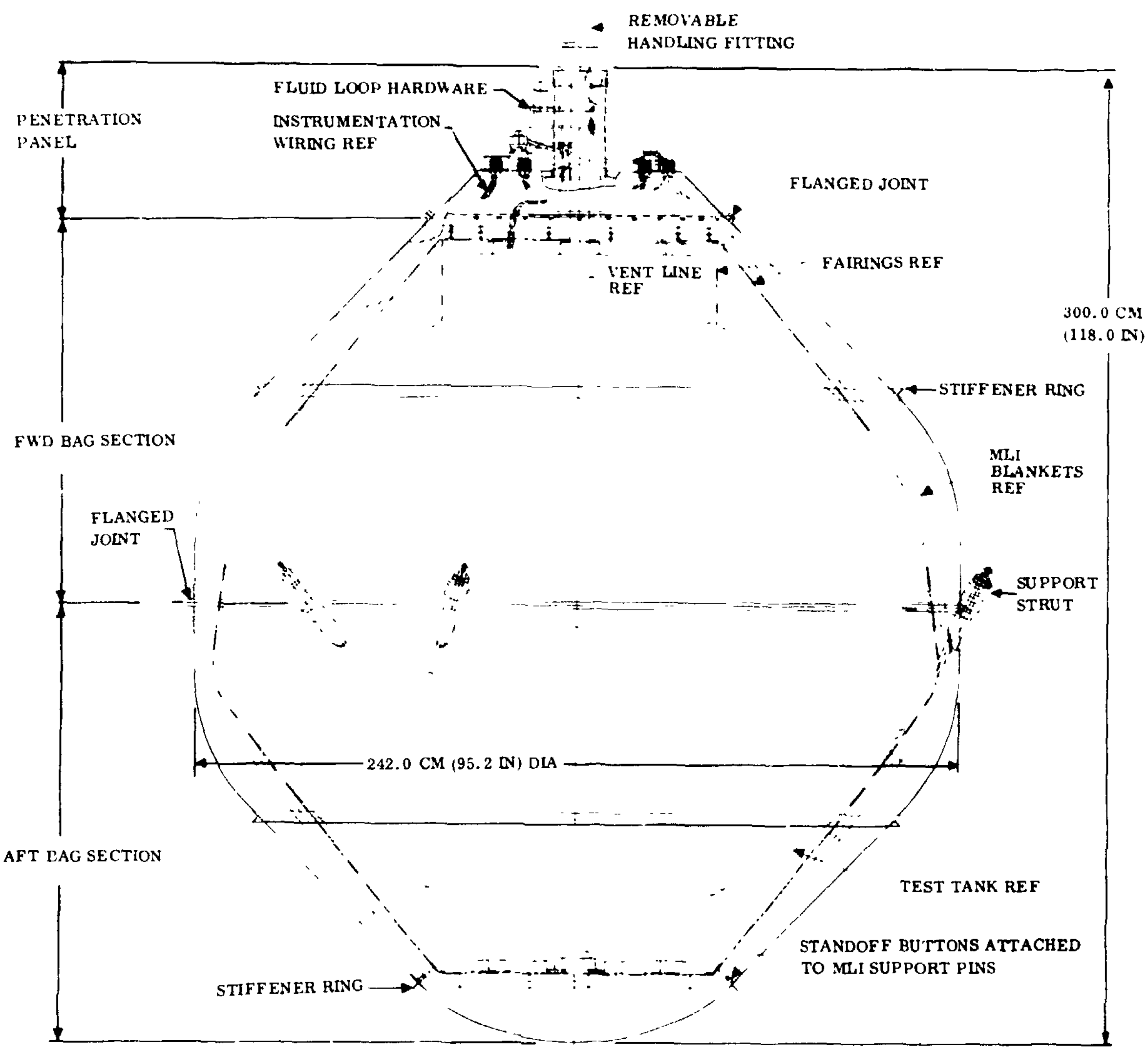


Figure S-1. MLI Purge/Repressurization General Arrangement

The bag is made of two plys of 181 style glass cloth preimpregnated with epoxy resin and bounded on each side by layers of FEP teflon. A reinforced flanged joint connects the tv ɩag sections. The reinforced epoxy fiberglass penetration panel joins the upper bag section also in a flanged joint. Provision is made in the lower bag half for six FEP teflon flexible boots which allow penetration through the bag wall by the tank support struts. Epoxy fiberglass stiffener rings are bonded to both sections of the thin walled bag to provide additional bag strength under both static and dynamic structural loading expected for a flight system. Prior to fabrication of any purge bag components, manufacturing plans were written to describe all aspects of manufacturing necessary to produce the bag. The plans are included as an appendix to this report.

Tools for producing the purge bag components were made from an epoxy fiberglass layup over plaster molds. The major tools required were those to make the purge bag halves and the reinforced penetration panel. Numerous simple small tools were employed to produce miscellaneous detailed parts such as bag stiffening rings, instrumentation supports, bag support duct, etc. The purge bag half tools were made in a three step process. Initially a male plaster "sweep" was made to the axisymmetric contour of the bag surface. Next a female plaster "splash" was formed over the male mold. Finally a male plastic tool was formed from a cured wet layup of 12 plys of epoxy fiberglass.

The fabrication of the purge bag shells began with the application of a layer of fluorinated ethylene propylene (FEP) over the surface of the bag tool. The preimpregnated epoxy glass fabric was applied over the FEP film in layers precut in gore sections. A second layer of FEP was applied over the outer laminate of glass fabric and the assembly cured in a one stage operation. Some difficulty was encountered in obtaining a tight fit of the FEP to the bag tool. This resulted in the development of some small wrinkles (maximum depth 0.076 cm) in the bag skin after vacuum/high temperature curing of the laminate. Future fabrication of a purge bag should consider the use of preformed FEP film for better fit to bag contour to improve bag appearance. Fabrication of the bag penetration panel was accomplished in a similar manner.

The manufacturing phase of the program was completed with the assembly of the insulated tank, purge bag, purge and vent hardware and support hardware into an integrated reusable cryogenic propellant storage system. Penetration of the tank support struts through the purge bag was accomplished by the use of flexible corrugated FEP boots bonded to the bag and clamped to the strut end. Sealing of the assembled purge bag against helium gas leakage was done through the use of an epoxy fiberglass strip bonded over the edge of the flange faying surfaces. In addition, the bolt holes in the bag flanges were counter sunk and epoxy fiberglass "buttons" potted over the holes to eliminate leakage paths. Both the flange faying surfaces and bolt heads were coated with a release agent to facilitate bag disassembly if necessary.

The purge, repressurization and vent hardware were selected to be flight proven. The valves and controls were mounted on the purge bag penetration panel at the upper end of the bag. The hardware consists basically of helium supply, bleed, vent and emergency pressure relief valves; pressure switch controls and valve filters. The instrumentation pass-throughs for the bag are also located on the penetration panel. The assembled MLI purge and repressurization system is a completely reusable cryogenic space storage system ready for subsequent testing at the Convair liquid hydrogen test site to determine thermal performance and life cycle characteristics.

INTRODUCTION

The use of cryogens in spacecraft requires the incorporation of a thermal protection system to minimize propellant heating and thus, increase propellant storage capability. The effectiveness of these protection systems is achieved by a series of radiation shields of low emissivity which are separated by low heat conducting spacers. Integration of such a multilayer insulation (MLI) system with vehicle tankage offers an opportunity to optimize the total structural and thermal systems of the vehicle from the standpoints of performance as well as manufacturability and maintenance. The development of the MLI and its design is strongly dependent upon the environment in which the system must function. In recent years much effort has been expended toward the development of MLI materials and design concepts applicable to derivatives of the Saturn V type space launch vehicles. These systems are characterized by single usage and moderate temperature environment requirements.

Convair Aerospace has developed a complete cryogenic propellant space storage system of Saturn V type. The system, developed under a division IRAD project, consists of a 2.21 m (87 in) diameter oblate spheroid aluminum tank insulated with 44 layers (two blankets) of aluminized Mylar Superfloc MLI and suspended by low-conductive fiberglass struts from an enclosing shroud. The total system was designed to withstand the Saturn V launch environment. A complete structural and thermal experimental program has verified that the flightweight system will meet all ground hold, boost, and space storage structural and thermal requirements.

Small-scale component and complete system tankage structural tests were conducted, including vibration, thermal and structural cycling, acoustic, and rapid evacuation tests. The tests were climaxed by a combined-environment (acceleration, vibration, thermal gradient, and rapid depressurization) test of a complete blanket insulation system on a 0.63 m (25 in) tank in the Convair Aerospace CEVAT centrifuge test facility. The CEVAT test successfully scaled up insulation system stress levels from the full-scale Saturn V vehicle to the small-size tank for proper simulation of the complete boost trajectory. Visual inspection of the system after CEVAT testing and comparison of pre-test and post-test space equilibrium boiloff measurements indicated no insulation system damage caused by the boost trajectory testing.

The complete, large-scale propellant space storage system was designed and built on the basis of scale-model test program results. It was completely tested in the 3.66 m (12 ft) diameter space simulation chamber. Tests included ground MLI purge system testing and heat leak studies, and space equilibrium thermal performance testing. The ρk product for this system at temperatures between 300 and 22 K (540 and 40 R) is 2.5×10^{-3} W kg/m^4 - K (9.02×10^{-5} Btu-lb/hr-ft^4 R).

The present insulation system is made of aluminized Mylar, which tests have shown to be unsatisfactory for the entry thermal environment of the Space Shuttle. Convair Aerospace has developed a modified Superfloc MLI concept under MSFC C[illegible] NAS8-26129 to meet the life and environmental requirements of the shuttle veh[illegible]. Th[illegible] study determined that goldized Kapton was the optimum MLI shield material. [illegible]her stru[illegible]ral modifications were made, including new blanket pin design and material, and a complete set of performance verification component tests to verify acceptability of the system for the shuttle.

Since the Mylar Superfloc MLI system cannot withstand shuttle environmental requirements, Convair Aerospace has designed, fabricated, and installed a completely new goldized Kapton MLI system on the 2.21 m (87 in) test tank. The new MLI system will meet all performance and structural requirements for Space Shuttle application, as defined by the results of the Cryogenic Insulation Development effort, Contract NAS8-26129.

The new MLI system by itself, however, would not provide a completely reusable propellant storage system for the Space Shuttle tankage. Because of the requirement to withstand the re-entry environment, the MLI must be repressurized during entry to neutralize the crushing atmospheric pressure loads. In addition, the MLI must be protected from repeated exposure to moisture from condensable gases in the atmosphere. An additional system was thus developed to provide: (1) ground purging of the MLI to remove condensable gases before cryogenic tanking, (2) venting of the MLI during boost and (3) repressurization of the MLI during atmospheric entry. With these functions added, the previously developed cryogenic space storage system will be completely reusable for Space Shuttle type missions.

The objective of this program is the development of a purge/repressurization system for a representative MLI system, suitable for 30 days storage of approximately 10,000 gallons LH_2 and 3700 gallons of LOX propellants and applicable to the Space Shuttle. The development of the purge system includes a survey and identification of existing suitable materials and components, concept definition, material selection and evaluation component tests, detail system design fabrication, installation and quality plans, assembly, and demonstration testing of a purge/repressurization and MLI system with cryogens. The purge/repressurization system referred to herein is defined as a purge jacket, purging requirements, valves, ducting, tubing, regulators, ground hold, and storage provisions, repressurization and pressurization techniques, and requirements necessary for ground ascent, re-entry, and landing conditions.

The program is being accomplished by the performance of the following six major tasks:

TASK 1 - Literature Survey. Currently available literature, related to MLI material, property data, evacua[illegible]n valves, repressurization and evacuation systems was reviewed. The survey determined [illegible]e availability of all necessary flightworthy components for the system. The findings of the survey are documented in Reference 5.

TASK 2 - Purge System Concepts. Concepts for purge systems capable of evacuation, pressurization and repressurization for representative liquid hydrogen tankage onboard a space vehicle during extended life cycle including multiple reuse were defined in References 5 and 6.

TASK 3 - Component and Materials Evaluation. Exploratory data acquisition and design verification scale model thermal and structural tests were conducted on purge system components, valves, joints, attachments and surface coatings to establish repeatability characteristics, materials compatibility to cyclic temperature environments, abrasive resistance of bag materials and/or coatings, and vent valve operations and seal characteristics.

TASK 4 - Purge System Design. Based on data from Tasks 1 through 3, the purge, repressurization, preconditioning and multilayer insulation systems were selected and assembly and detail drawings prepared. The design evolved represented a total integrated system design suitable for both the LOX/LH_2 tanks on the Space Shuttle and flightworthy in an environment up to 450 K (350 F).

Structural, weight, thermal, gas flow, and material analyses and tests were performed to assure system compatibility with expected Space Shuttle environments.

TASK 5 - Manufacturing Development. Assembly sequence drawing an[illegible]ngs for all tooling and fixtures required to fabricate the purge and repressuriz[illegible]system and the necessary provisons for cross-country shipments were established. [illegible] manufacturing plan, including sequence, quality control and inspection provisions affecting the design for the installation of the purge and repressurization system onto the Convair Aerospace Division 2.21 m (87 in) diameter tank, were developed.

TASK 6 - Fabrication, Test and System Evaluation. A preconditioning, purge and repressurization system was fabricated in conjunction with a multilayer insulation concept as determined from the results of Tasks 1 through 5. Documentation for instrumentation, installation, and output location and function will be prepared for the proposed tank test of the total MLI system. A test plan will be formulated for the purge and repressurization system to include the test specimen definition, instrumentation definition and requirements, and data processing and correlation methods. A functional test will be performed on the test specimen proposed in Task 4 to demonstrate the total system's performance. The total system will be evaluated and a test report prepared. The evaluation shall include the system's performance penalties and a summary of its compatibility with the Space Shuttle environments.

The program master schedule is shown on Figure 1.

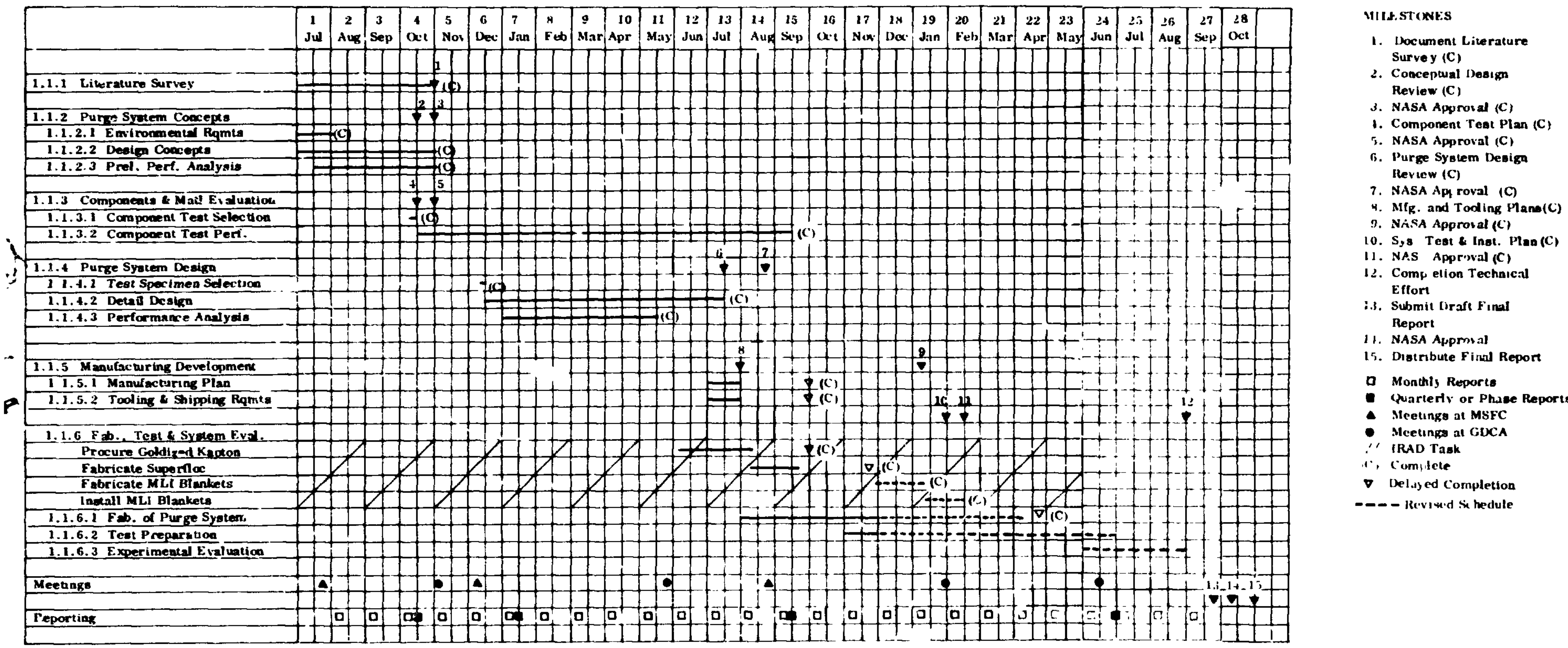


Figure 1. Pressure and Repressurization Purge System for Reusable Space Shuttle Multilayer Insulation Program Master Schedule

2

MULTILAYER INSULATION SYSTEM FABRICATION (IRAD TASK)

The multilayer insulation system (MLI) chosen for use on the 2.21 meter diameter liquid hydrogen test tank was Superfloc. The insulated tank became the cryogenic storage vessel for the purge and repressurization system performance demonstration test article. The MLI consisted of two blankets, each with 22 layers of goldized Kapton Superfloc. Load carrying face sheets for the blankets were made of a polyimide resin reinforced with beta glass cloth. Each blanket was arranged around the circumference of the tank in 12 gores with butt joint seams. The seams for the two blanket layers were overlapped to prevent radiant energy tunnelling directly to the tank.

The Superfloc MLI system was designed and fabricated as part of the continuing Convair IRAD program conducting research on cryogenic insulation systems (Reference 1).

2.1 SUPERFLOC MANUFACTURE

The fabrication of the Superfloc MLI was facilitated by the development of a detailed manufacturing instruction. The instruction includes the material requirements; manufacturing equipment description; manufacturing environment, safety and cleanliness requirements; adhesive silk screening description; flocking techniques; MLI curing requirements; and quality control procedures. The detailed instruction is contained in Reference 1.

The Superflocing operation was performed in controlled environment facility (Figure 2). The relative humidity was controlled between 40–60% and the temperature at 297 K ± 0.55K (75F ± 1F). The Superflocing begins by taping the goldized Kapton to a handling device for later silk screening (Figure 3). This procedure allows the Superfloc to be manufactured in any lengths or widths compatible with the available metalized plastic films.

Application of adhesive to the goldized Kapton sheets for later flocking is accomplished using a perforated silk screen printing technique (Figure 4).

Continuous application of adhesive dots to the plastic film is accomplished by repositioning the silk screen along the film sheet after each adhesive screening pass with the squeegee.

Figure 2. Controlled Environment Superfloc Manufacturing Facility

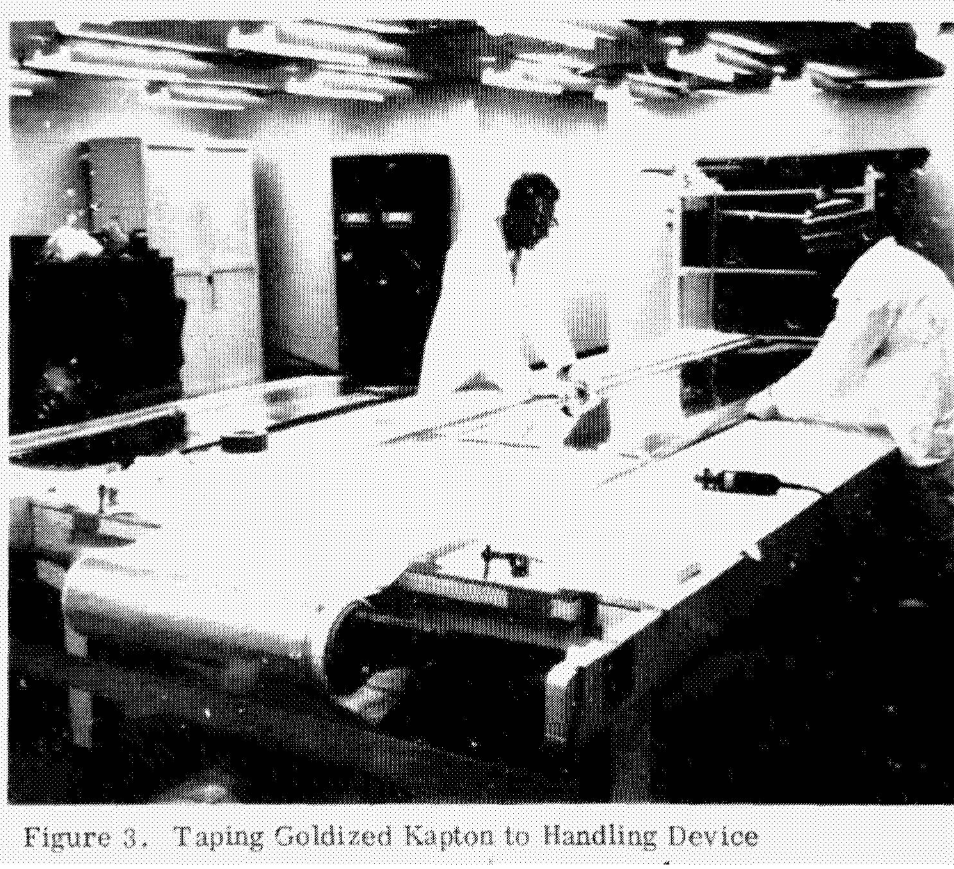
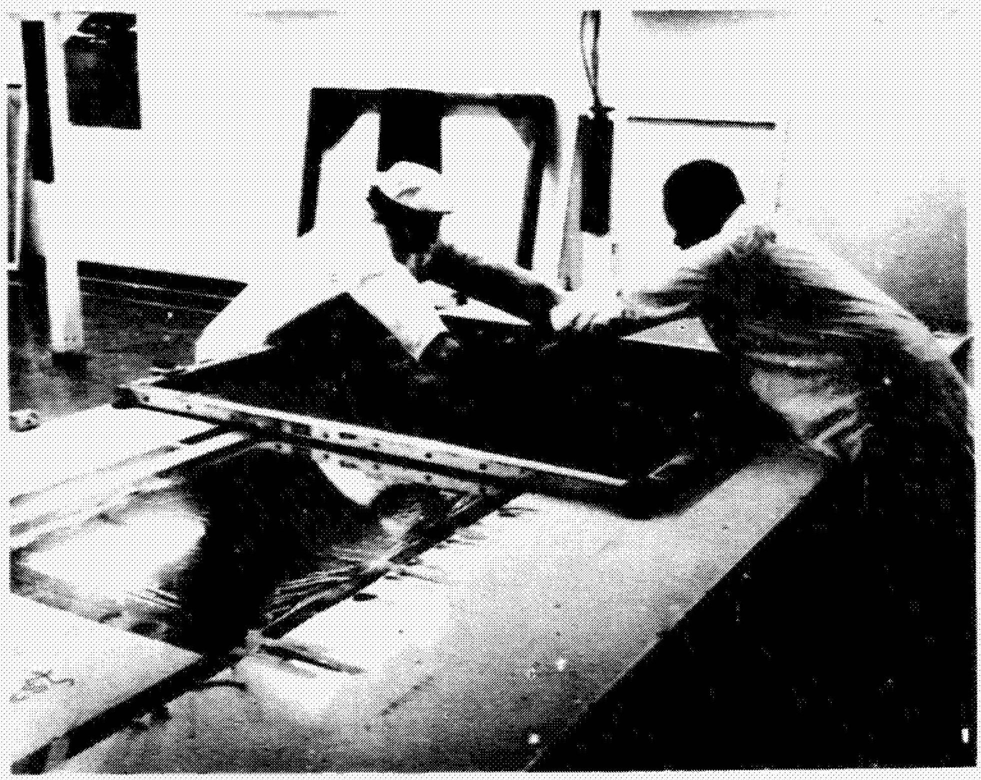


Figure 3. Taping Goldized Kapton to Handling Device



gure 4. Silk Screen Printing Adhesive Dots on Goldized Kapton

Actual ocking of the goldized Kapton is accomplished by running the sheets cover with adhesive dots through a vibrator machine where the Dacron flock need attach to the adhesive (Figure 5).

Following the application of the flock to the goldized Kapton, the completed Superfloc sheets are allowed to cure for 24 hours before they are used in MLI blanket fabrication.

2.2 MLI BLANKET FABRICATION

The MLI blankets for the test tank are made in 0.529 radian (30°) gore sections each with 22 layers of goldized Kapton Superfloc reflective shields and load carrying face sheets of a beta glass reinforced polyimide. Flat cap blankets of the same materials were used at the top and bottom areas of the tank and intersected the gore sections in a butt joint. Details of the blanket design configuration are contained in Reference 2. Two blanket layers (44 reflective shields) are used on the tank.

2.2.1 <u>BLANKET FACE SHEET</u>. The high temperature compatibility requirement selected for the MLI required the development of a new material for the load carrying blanket face sheets, (References 1, 3, 4). A DuPont polyimide resin (Pyre ML) was u d, reinforced with beta glass cloth fibers. A male aluminum

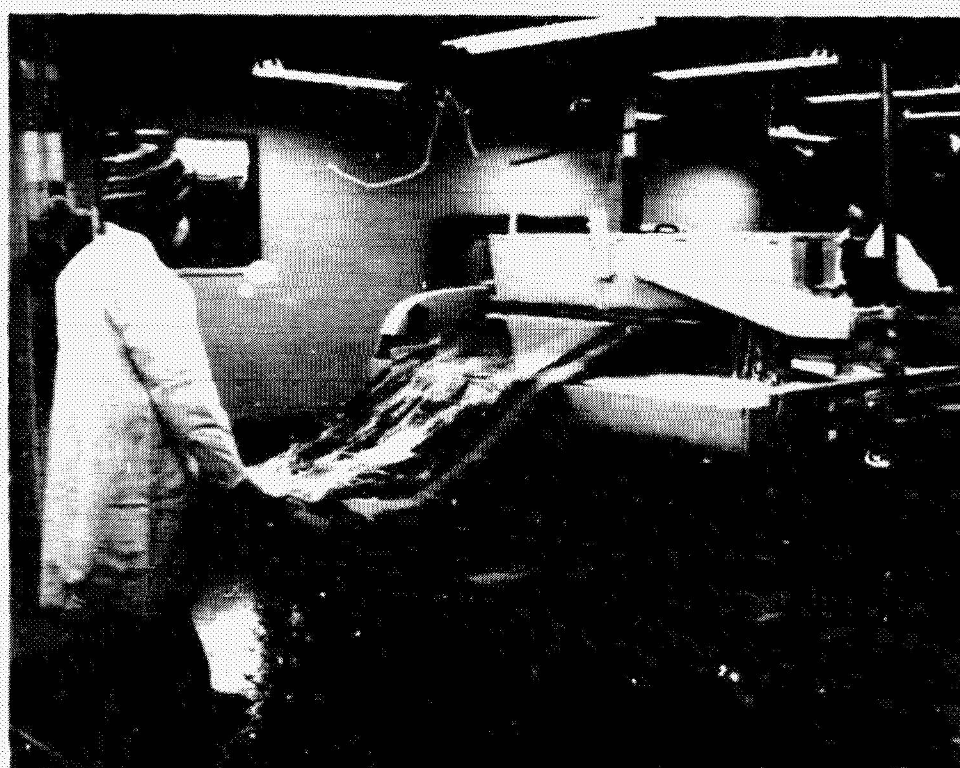


Figure 5. Applying Dacron Tufts to the Adhesive Dots

tool in the shape of a blanket gore was covered with Mylar sheets to act as a "release agent." The polyimide resin was painted over the Mylar, the beta glass cloth imbedded in the resin and the composite oven cured (Figure 6).

The finished face sheet thus has a permanent shape in the form of the tank fairing contour.

2.2.2 BLANKET LAYUP. The layup of the gore sections of the MLI blankets was conducted on hard epoxy fiberglass tooling. Strips of polyurethane foam were added on four levels of the blanket layup to provide sufficient sitffness to permit drilling and trimming without tearing the Kapton (Figure 7).

The goldized Kapton Superfloc sheets were laid on the tool, trimmed roughly to the shape of the tool and taped in place to the outer tubular frame of the female tool half. A smooth formed contour of the core sheets to the compound gore curvature was achieved by using a darting and taping technique (Figure 8). The pleats formed by the darting tool were taped in place with goldized Kapton tape.

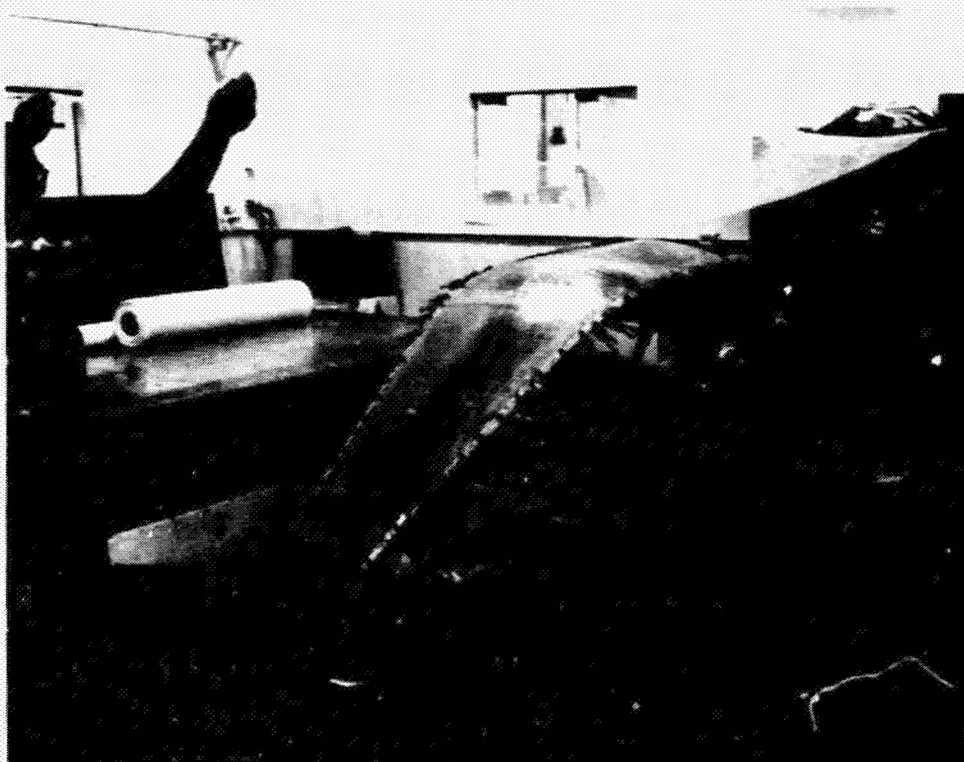


Figure 6. Layup of Load Carrying Face Sheet for MLI Blanket Gore

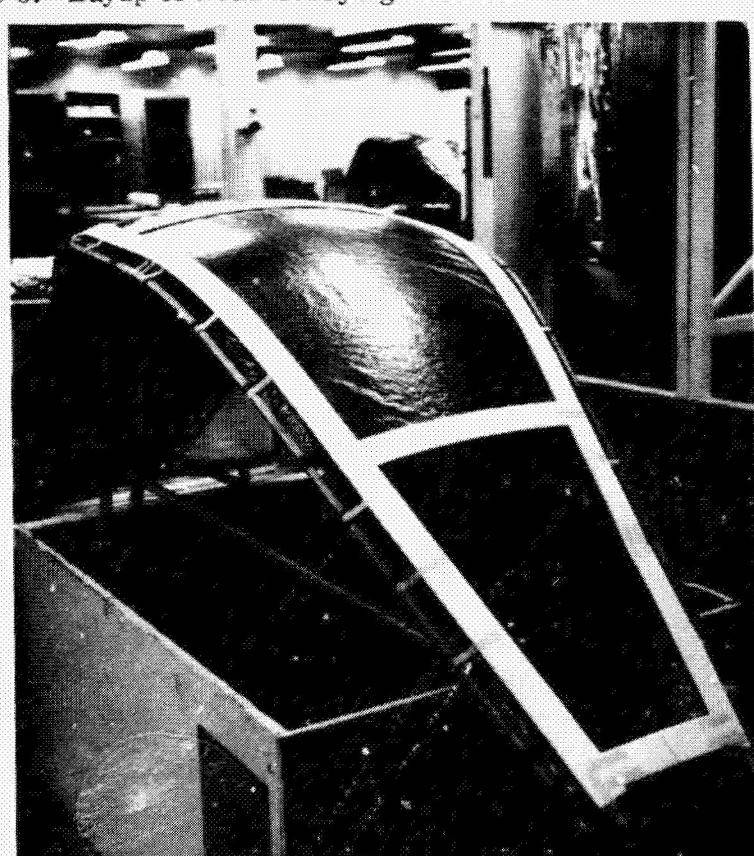


Figure 7. Blanket Layup Operation - Inner Face Sheet

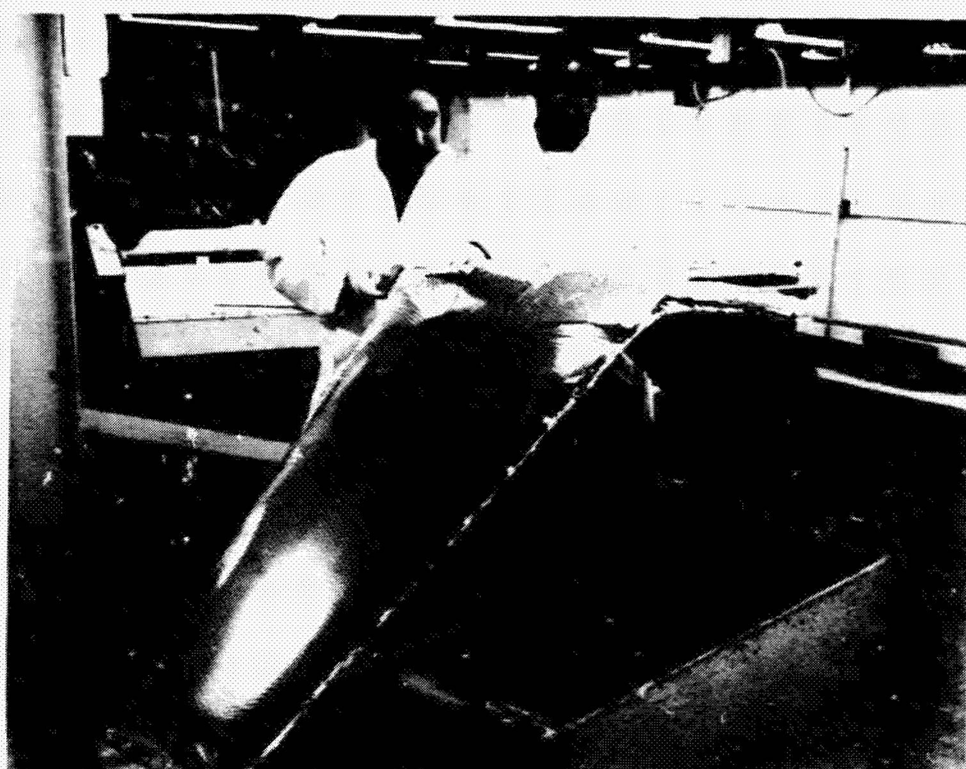


Figure 8. Pleating Operation

Following the gore blanket layup, the covering male gore tool was put in place. The blanket gores were trimmed to final shape in the tool, and holes drilled in the MLI layers to accommodate mounting and purging pins used at blanket installation.

The final step in blanket assembly involved the installation of triangular polyphenylene oxide (PPO) tabs to the face sheets of the blanket gore and the inclusion of a thru grommet heat swaged to the tabs (Figure 9).

The PPO tabs were bonded to face sheets using Crest 7343 adhesive modified with Silane to provide better high temperature strength. Heat swaging of the grommets was accomplished using a modified soldering iron.

2.3 MLI BLANKET INSTALLATION

Installation of the MLI blankets to the test tank was started by handing the first eleven of inner blanket gores over the purge and support pins on the upper and lower ends of the fiberglass fairings for the 2.21m test tank (Figure 10). The final gore was trimmed at assembly to compensate for any accumulated manufacturing tolerances and allow a tight butt joint at the final blanket closure. The test tank with one complete MLI blanket layer installed is shown in Figure 11. The blanket gore joints are held together with twin pin fasteners. The insulation purge pins can be seen protruding through the

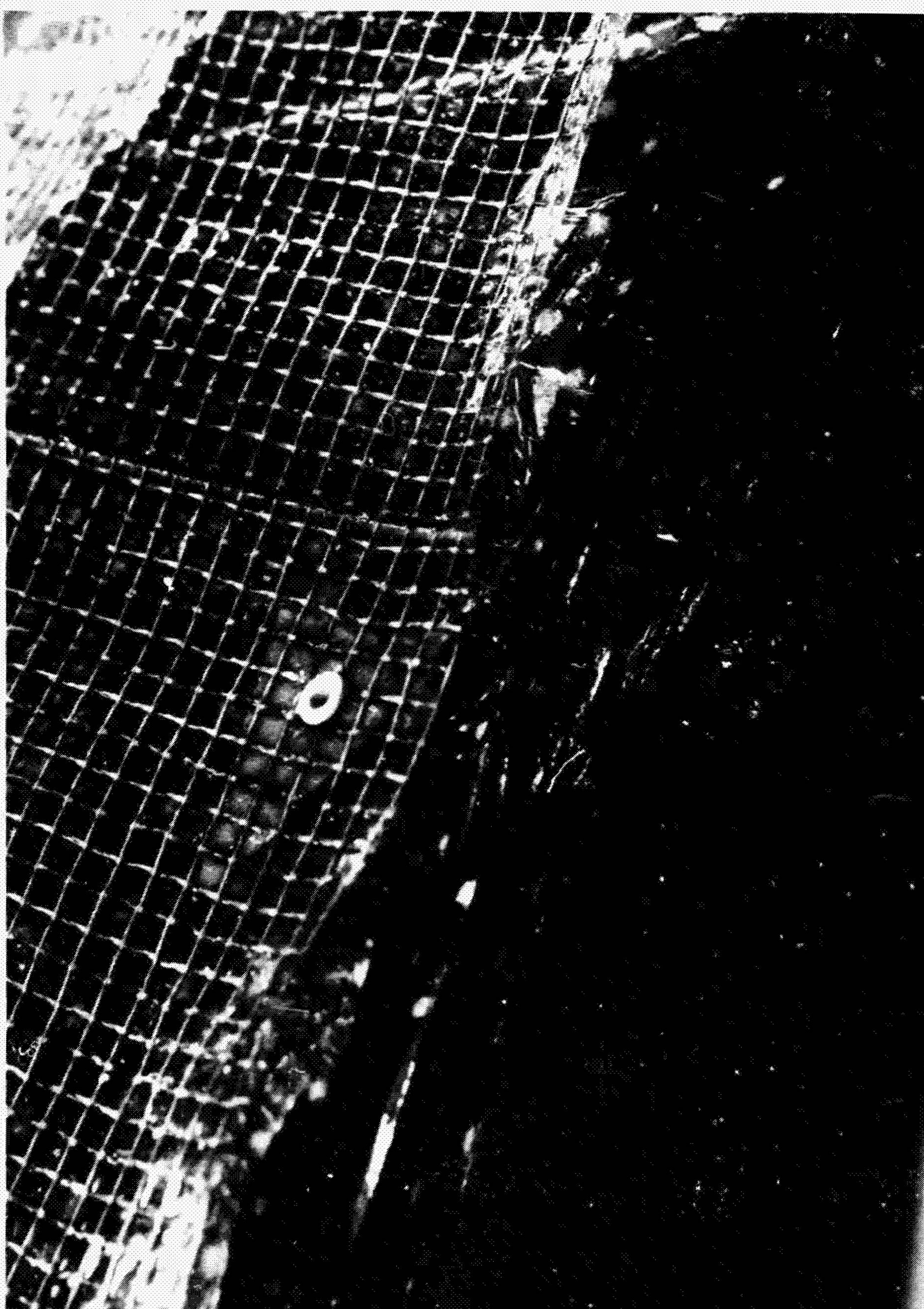


Figure 9. Blanket Tab and Grommet Installation

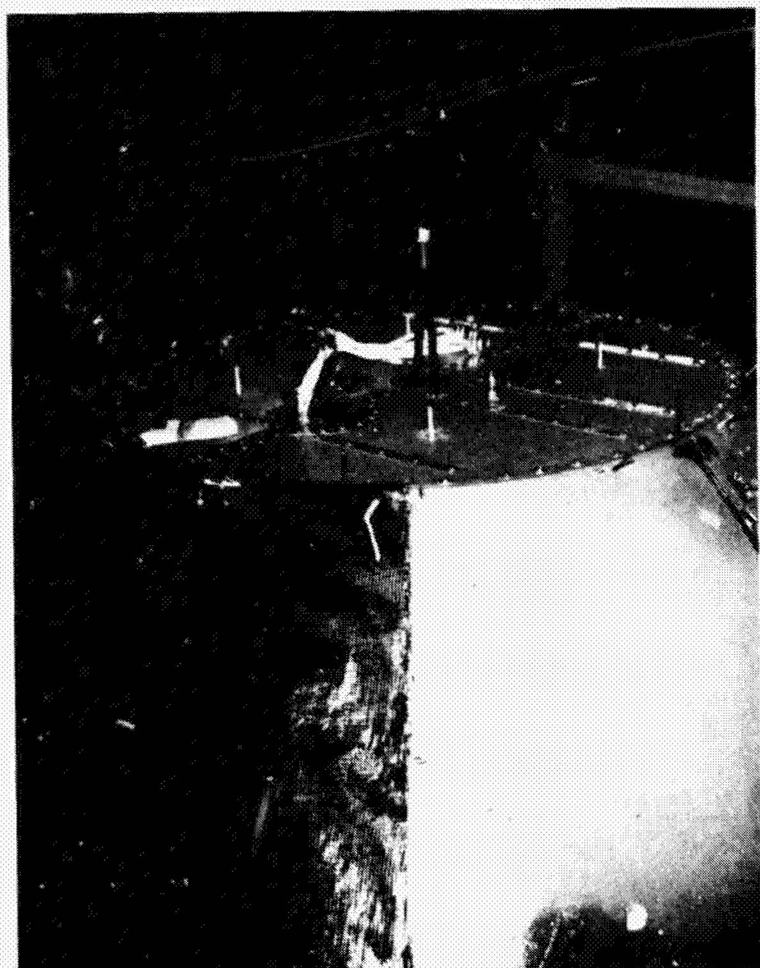


Figure 10. Installation of MLI Blankets to Fairings of Test Tank

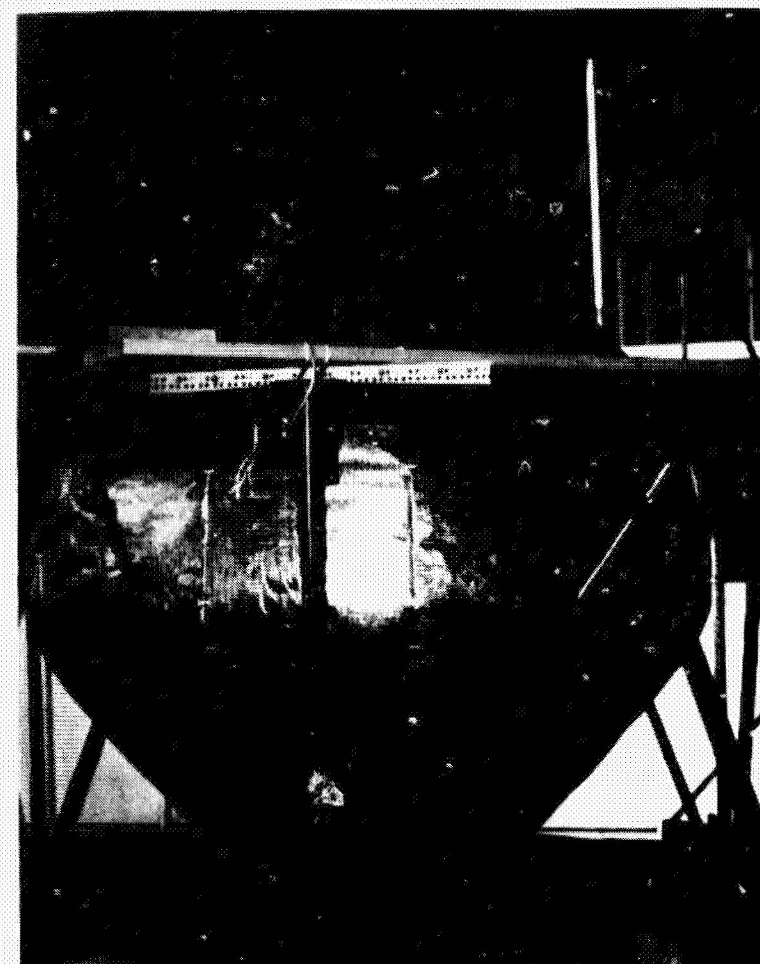


Figure 11. Test Tank With Inner MLI Blanket Layer Installed

inner blanket layer. The outer blanket layer contains matching holes under the outer face sheet to also accept the purge pins. Support pins at the top and bottom of the blanket gore sections mount both the inner and outer blankets. The twin pin fasteners are joined by the use of a connecting link and the ends of the pins heat swaged to form a link retainer (Figure 12). The butt joint seams for the inner and outer blanket layers were overlapped 2.54 cm (1 in) to eliminate the problem of radiation energy "tunnelling" through the butt joints directly to the cryogenic tank.

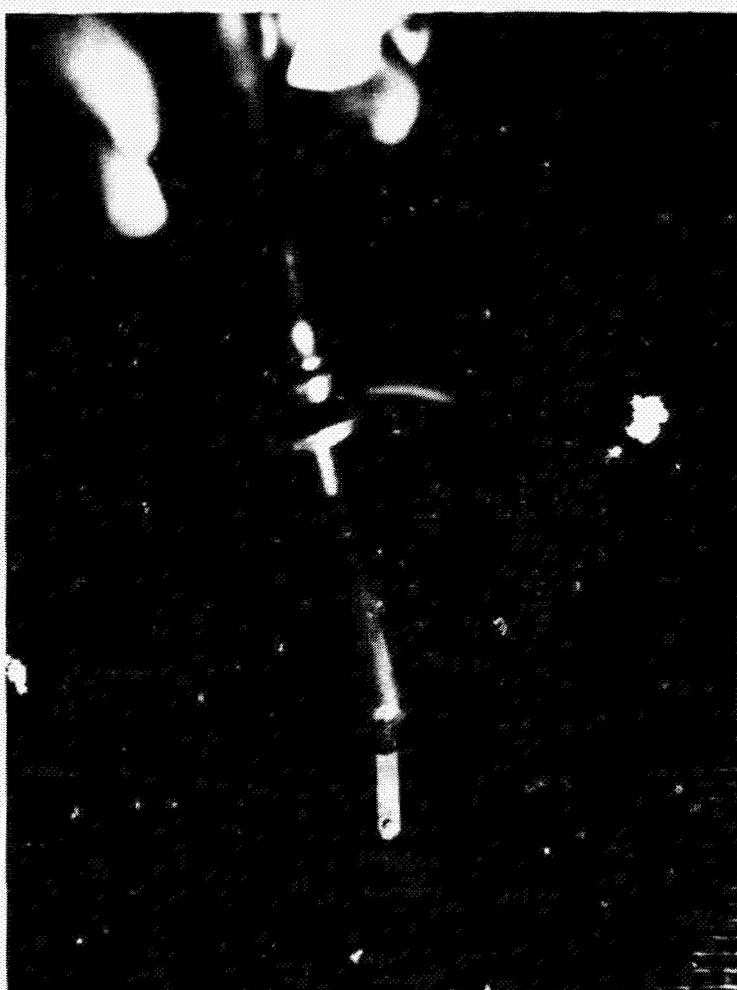


Figure 12. Heat Swaging Links to Twin Pin Fasteners

The cap flat blankets on top and bottom of the tank were installed in a manner similar to that described above for the gore sections. The joints between blanket sections were selectively taped across the seam where necessary to close any small gaps which were present to prevent radiation energy tunnelling into the blanket. The goldized Kapton tape pieces were used sparingly to assure that no interference would be found to MLI venting during life cycle testing. The flight configuration insulated tank was fitted with low conduction fiberglass support struts for later thermal performance testing.

3

PURGE SYSTEM FABRICATION

The total reusable cryogenic propellant storage system used for this program consists of the MLI covered 2.21m cryogenic tank,the fiberglass bag which encloses the tank and the purge and repressurization valves, filters and controls. The total system was designed by GDCA and the necessary hardware fabricated or procured and assembled into the complete large scale test article to be used for MLI purge and repressurization feasibility, life and performance demonstration testing.

3.1 PURGE BAG DESCRIPTION

The purge bag used with the MLI purge and repressurization subsystem is designed to provide an enclosure around the MLI during ground purging with gaseous helium; to provide a receptacle for MLI repressurization gas during atmospheric re-entry; to provide a protective enclosure for the MLI during repeated flight and maintenance cycles; and to provide a closed container for inerting gas (helium) during vehicle storage periods. The configuration of the MLI purge and repressurization system is shown in Figure 13. As can be seen, the purge bag is made of three sections; two thin wall bag sections and a reinforced penetration panel which supports the fluid loop hardware for the purge, vent and repressurization subsystems. The design details of the assembly are contained in the report on the results of the design phase of the study (Reference 2).

The fabricated larg › scale configuration of the purge bag evolved from materials and subscale bag manufacturing and structural tests which were performed as part of the task 3 - component and material evaluation portion of the study (Reference 2). The bag is made of two plys of 181 style glass cloth preimpregnated with epoxy resin and bounded on each side by layers of FEP teflon. A reinforced flanged joint connects the two bag sections. The reinforced epoxy fiberglass penetration panel joins the upper bag section also in a flanged joint. Provision is made in the lower bag half for six FEP teflon flexible boots which allow penetration of the tank support struts through the bag wall. Epoxy fiberglass stiffener rings are bonded to both sections of the thin walled bag to provide additional bag strength under both static and dynamic structural loading expected for a flight system.

3.2 PURGE BAG TOOLING

The tooling concept for fabrication of the purge bag was established as a result of a manufacturing test conducted for an 0.61 m diameter subscale purge bag (Reference 2). It was determined that plastic tooling would be required to produce the desired

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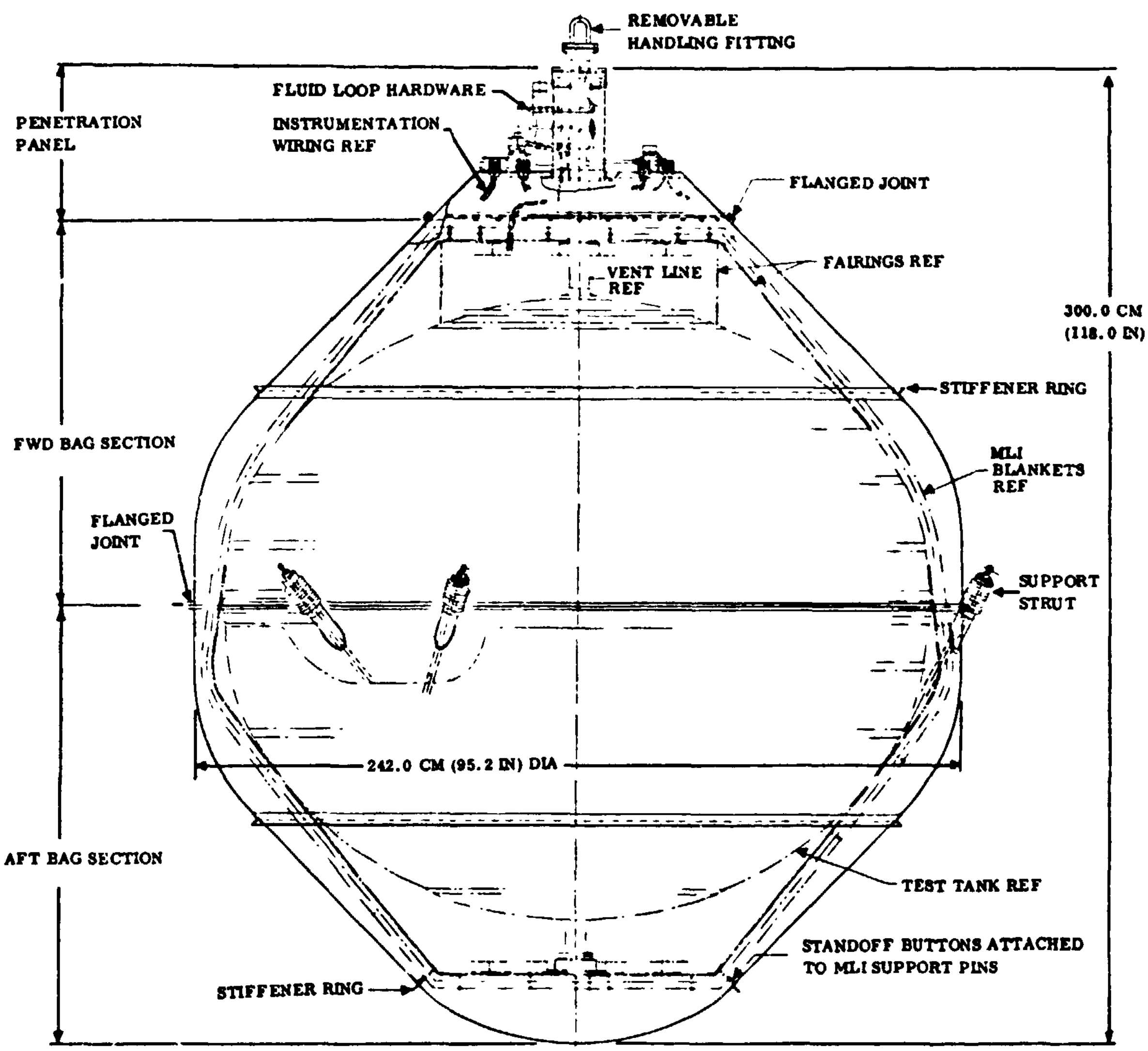

Figure 13. MLI Purge/Repressurization General Arrangement

molded layup of epoxy fiberglass and FEP teflon. However, to produce the plastic tooling it was necessary to fabricate a plaster mole in the shape of a bag section for plastic tooling layup and oven curing.

Two major tools and several minor ones were used to perform the purge bag fabrication. The largest of the major tools was in the form of a purge half shell. Since the bag is axisymmetric a template was fabricated from a steel sheet which followed the purge bag contour from girth flange to bag apex. The template became part of a sweep fixture for forming a full plaster replica of the purge bag half shape (Figure 14).

A tubular steel and wire mesh substructure was formed in the approximate shape of the purge bag half to serve as support for the plaster mockup of the purge bag. The

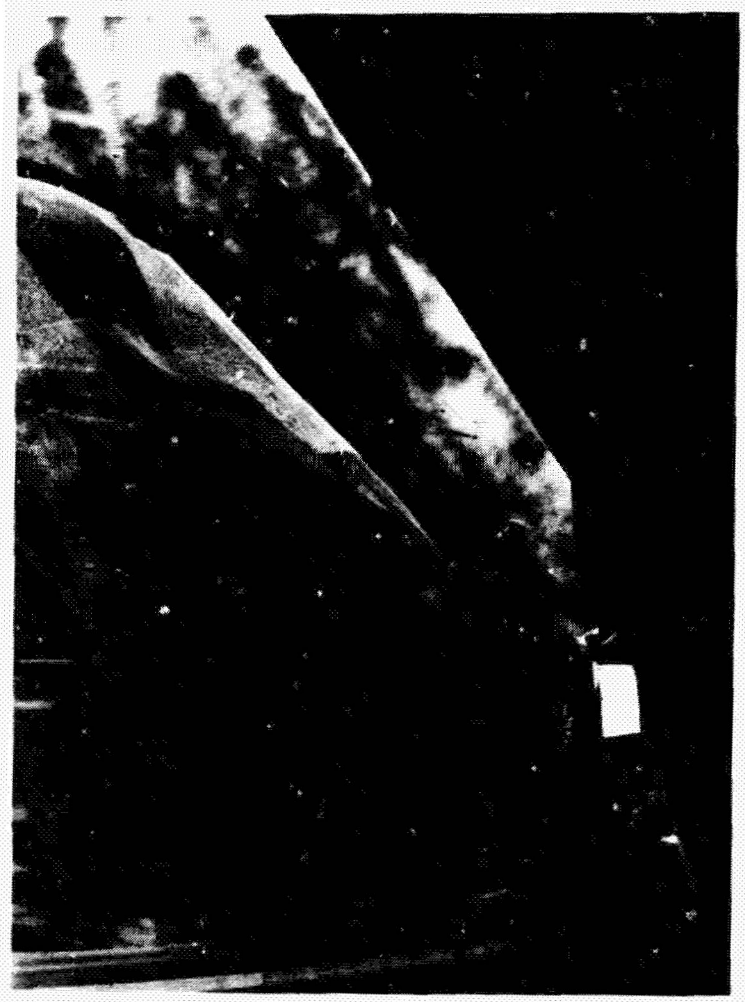

Figure 14. Sweep Template for Purge Bag Half Plaster Mockup

bag contour template was mounted on a track surrounding the mesh substructure so the template could make a complete sweep around the structure (Figure 15). Plaster was applied to the mesh substructure and a sweep made with the template to form a complete plaster mockup of the bag contour (Figure 16).

The size of the purge bag made it imperative that the final layup of the bag plys on the plastic tooling be accomplished on a male plastic tool. For this reason, it was necessary to fabricate a second interim plaster tool to act as a base for forming and oven curing the male plastic tool. A second plaster mockup was thus made in the form of a "splash" over the cured male plaster mockup. Parting agents were placed on the male mockup surface to assure that the fresh plaster applied on the surface for the female mockup would be easily removable when the plaster fully cured. Initially a coating of Furnance Release F was placed over the plaster male mockup to act as both a seal for the plaster pores and a release agent. A coating of Valco 550 wax was then rubbed on the form followed by a coating of PVA release agent. The PVA material is water soluable which allows easy clean-up following removal of the female "splash" from the male mold. A circular steel tubular structure was fabricated to act as support and provide handling for the female plaster bag mockup.

The steel structure was put in place around the male mockup, plaster spread over the mockup and female splash formed to the contour of the purge bag. The cured plaster female bag contour mockup is shown in Figure 17.

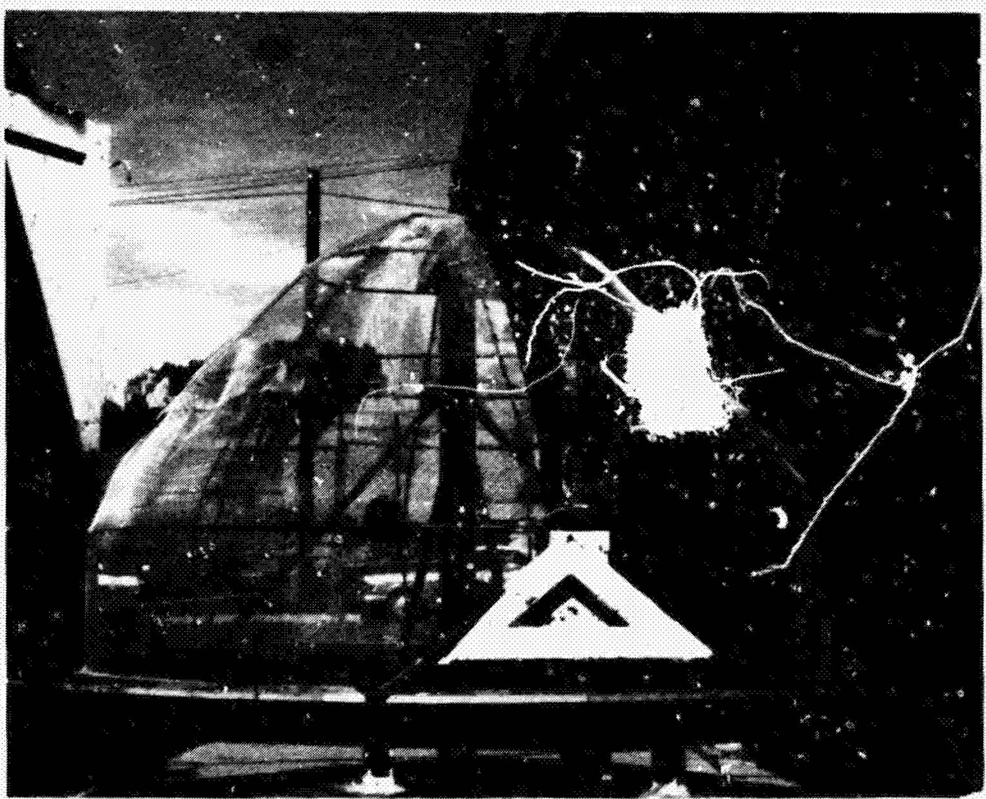

Figure 15. Plaster Mockup Sweep Tool

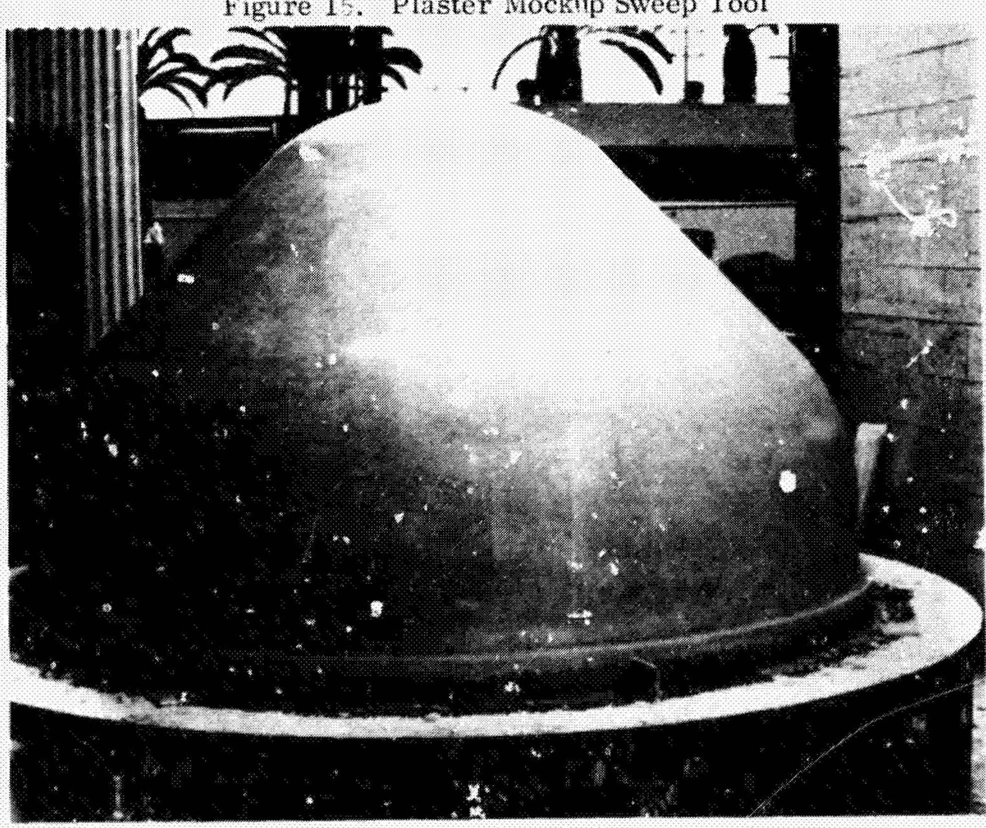

Figure 16. Male Plaster Mockup of Purge Bag Contour

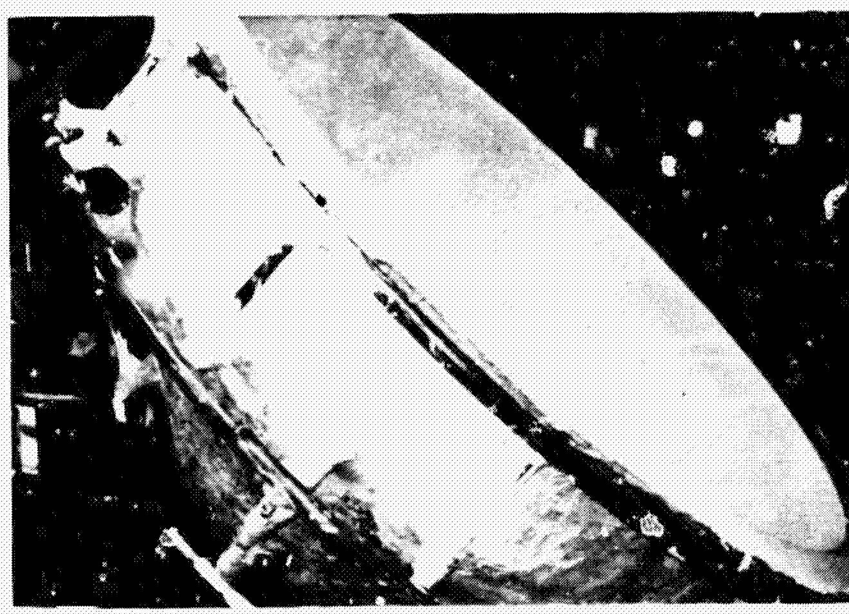

Figure 17. Female Plaster Mockup of Purge Bag Contour

The final tool used for actually fabricating the purge bag shells was made from a wet layup of 12 plys of fiberglass cloth using Fiber Resin 5422M and Fiber Hardener 5412C. The composite was cured under vacuum pressure at temperatures exceeding 425K. The completed plastic tool thus had the convex contour of the bag.

The second major tool built was the purge bag penetration panel tool. The fabrication technique was similar to that used for the bag contour tool. Initially a plaster sweep was made in the shape of the door contour. The plaster mockup was prepared for fiberglass layup in the manner described above. The tooling cloth was laid over the ring shape plaster mold, vacuum bagged and cured at elevated temperature to form the plastic tool in which the actual penetration panel was later made. The epoxy pre-impregnated glass cloth layup over the plaster mold is shown in Figure 18. Portions of the lower half of the vacuum bag can be seen at the edge of the tool layup.

The cured tool is seen in Figure 19. Portions of the plaster mockup for the tool form are still contained over the tool surface. Tooling marks are seen on the top tool surface which indicate the locations for mounting holes required in the finished penetration panel. Removable aluminum plugs (not shown) were utilized at the hole locations during portions of the part layup and curing cycle to precisely position penetrations during fabrication.

Several minor tools were also fabricated from epoxy fiberglass laminate to produce miscellaneous parts such as tubes, stiffening rings and instrumentation support brackets. Several of these small tools are shown in Figures 20 and 21.

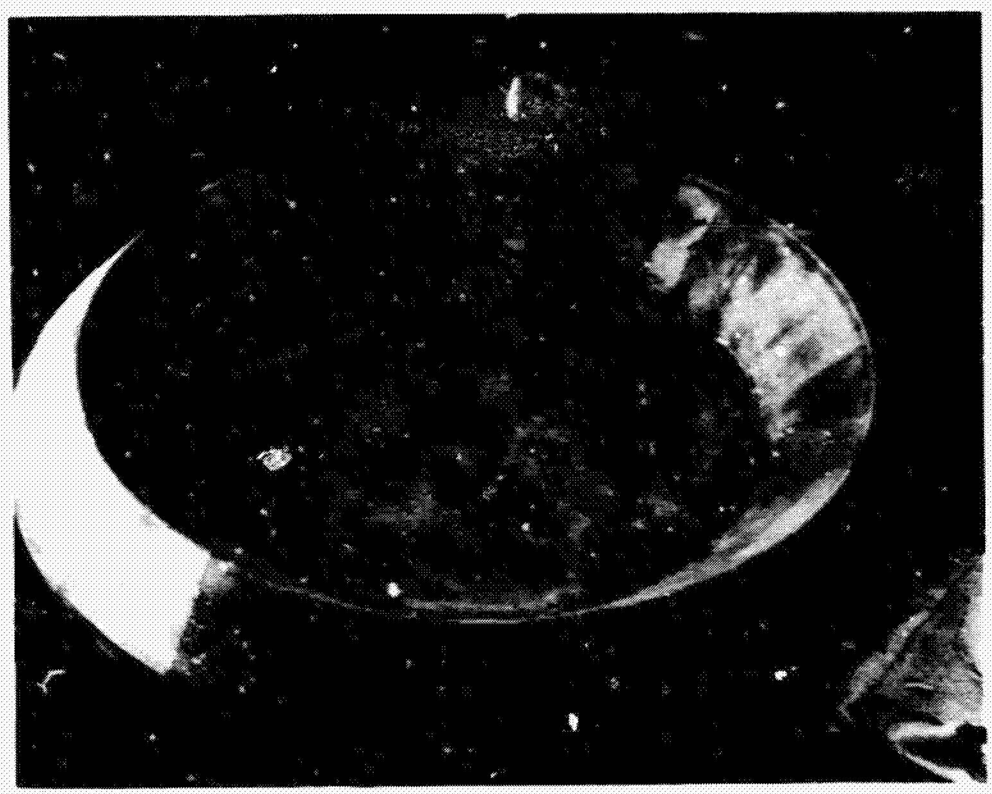

Figure 18. Plastic Tool Layup for Penetration Panel

Figure 19. Cured Penetration Panel Tool With
Plaster Mold Partially Removed

Figure 20. Purge Bag Support Tube Tool

Figure 21. Purge Bag Bottom Stiffening Ring Tool

3.3 PURGE BAG FABRICATION

The actual fabrication of the purge bag and tooling was accomplished by DEMCO of National City, California under subcontract from GDCA. The fabrication was accomplished in accordance with manufacturing plans which were prepared by GDCA, approved by NASA and furnished to the vendor. The manufacturing plans are included in this report as Appendix A. The purge bag is constructed of epoxy fiberglass plys sandwiched between layers of FEP teflon. A preimpregnated epoxy glass fabric style 181, Stanpreg VET-HR Epoxy Resin with Volan A finish, was used for all fiberglass part layup. The teflon skins on each side of all bag surfaces was fluorinated ethylene propylene (FEP) Type II cementable on both sides (0.0508 mm thick) as manufactured by DuPont. The basic bag structure was made using two plys of glass fabric with reinforced stiffened areas near flanges and structural penetrations using up to six plys of fabric. The purge bag penetration panel or door contained numerous instrumentation penetrations and hardware mounting provisions. The door was thus stiffened to a thickness of 1.9 cm on its flat surface and contained 6 plys (approximately 0.122 cm thickness) on the conical portion between door mounting flange and flat hardware mounting surface.

The fabrication of the purge bag shells began with the application of a layer of FEP over the surface of the bag tool. The FEP was cut to gore shapes with an end cap at the spherical portion of the contour (top of tool). To eliminate epoxy resin bleed through unto the tool at the FEP seams, it was necessary to seal the gore seams. Heat sealing had proven ineffective and a technique was developed using double stick tape to seal the seam during oven cure of the laminate (Figure 22). Initial application of the FEP film over the tool is shown in Figure 23. As can be seen, it was very difficult to obtain a completely form fitted layup of the FEP film.

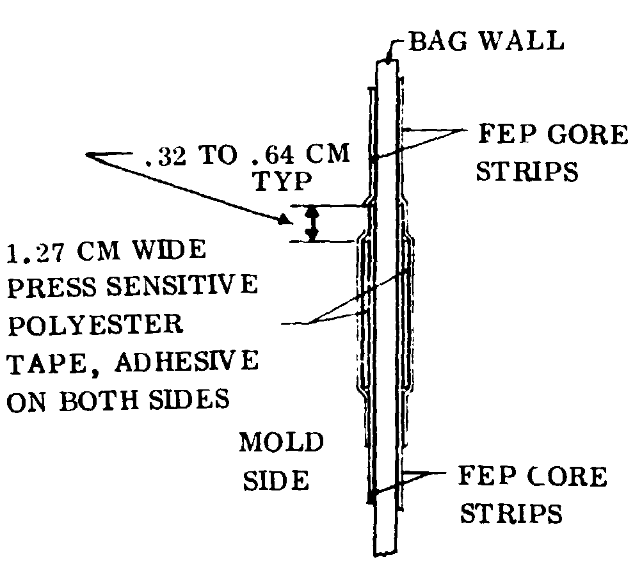

Figure 22. Typical FEP Film Joint

The preimpregnated epoxy glass fabric was applied over the FEP film in layers to obtain location required by the manufacturing drawings. The fabric was also cut in approximate gore sections, however a slight overlap was allowed at the intersection of gore edges. The local areas of structural stiffening required on the bag skin were obtained by blending the fabric thickness in a step fashion from the 2 ply nominal thickness to the 6 ply reinforced thickness. The nominal thickness for the flanges used on the sections of the purge bag is 1.27 cm. To facilitate the layup of the flanges and bag skin in one operation, a precured laminated ring of epoxy glass was fabricated.

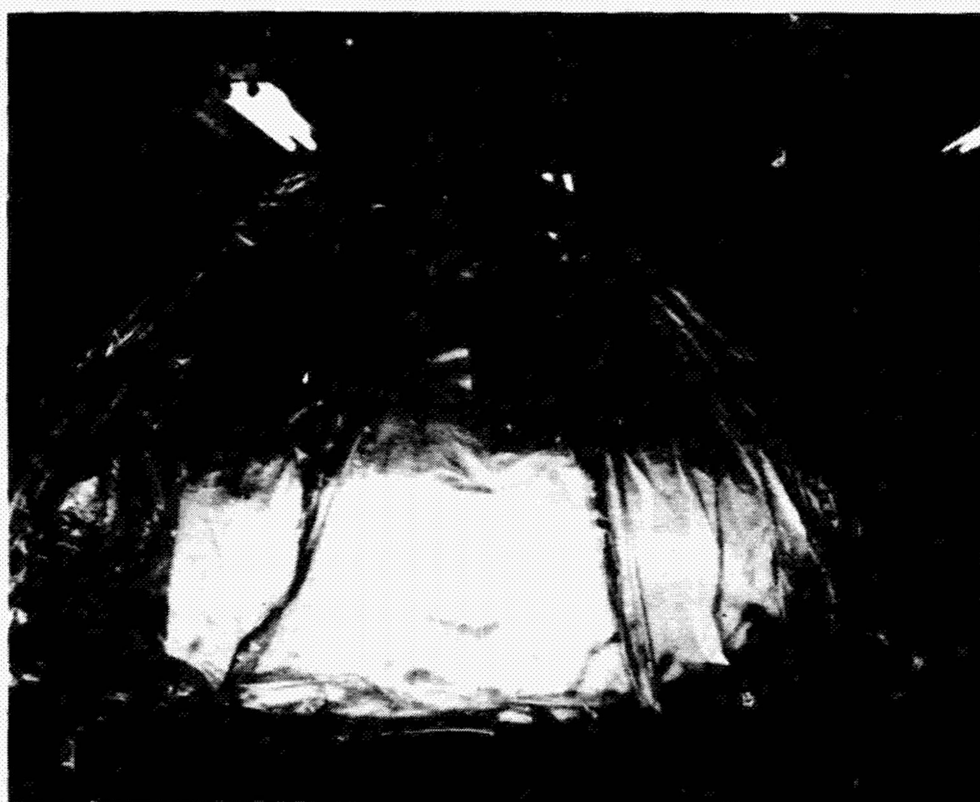

Figure 23. Application of FEP Film to Bag Tool

The ring was used as an insert between surface fabric plys to form the proper flange thickness. Figure 24 shows a description of the technique used for flange layup.

The layup of the purge bag halves was completed with the application of the outer skin of FEP. The entire assembly was then "vacuum bagged" and cured in accordance with the procedures of the manufacturing plan (Appendix A). The fabrication techniques were similar for both halves of the bag except that for the top bag half the layup tool was modified to allow the inclusion of the mating flange for the penetration panel. Before each half of the bag was removed from the layup tool the epoxy glass stiffening rings were bonded to the outer surface of the bag. The FEP film was removed on the outer bag surface in the stiffener ring area to facilitate a good bond between ring and bag. Hysol 934 epoxy based adhesive was used for all bonding. The completed bag halves are shown in Figure 25. The bag is resting on the penetration panel flange. The girth flanges

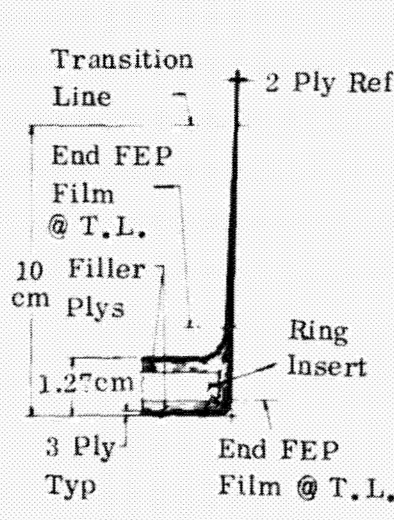

Figure 24. Typical Girth Flange Layup

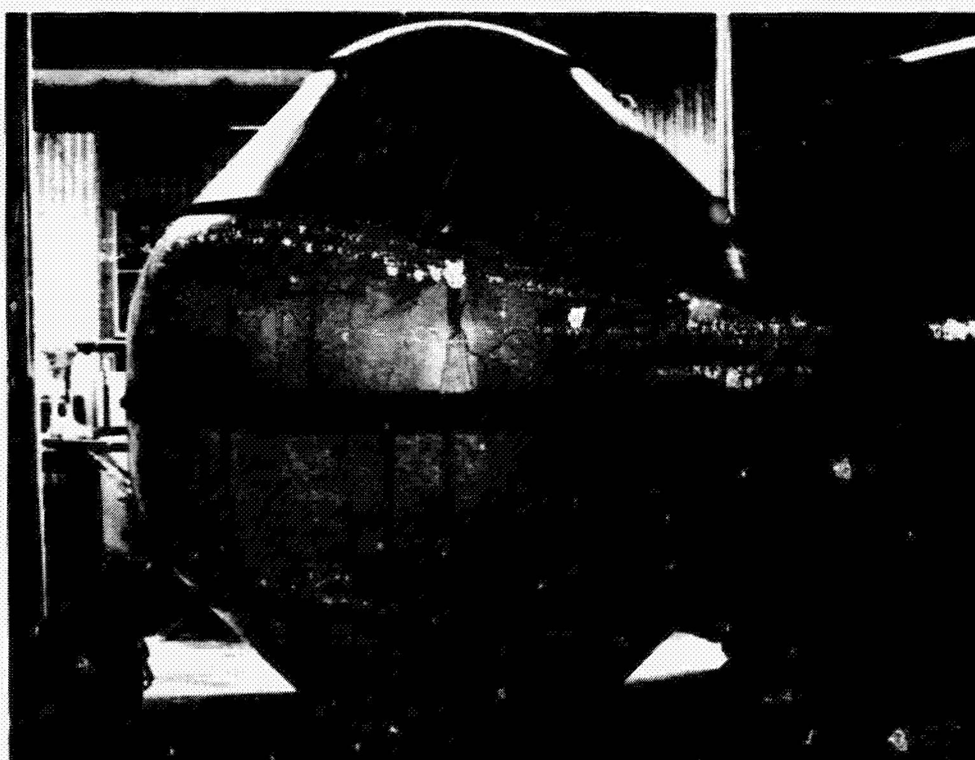

Figure 25. Completed Purge Bag Halves

and stiffening rings are readily apparent. The stiffened wall areas adjacent to the flanges and at the tank support strut penetration points are noted as darkened areas on the back lighted photograph. The slightly darkened vertical markings are areas of glass fabric gore section overlap during bag layup.

One fabrication problem which became evident was that associated with the application of the FEP film during bag layup. Due to the inability to get the FEP film to fit tightly about the layup tool, wrinkles were forced into the bag surface during the curing cycle at vacuum pressure. The maximum depth of any wrinkle was 0.076 cm. The wrinkling did not affect the structural integrity of the bag, but it did affect the bag appearance. Future fabrication of a purge bag should consider the use of a preformed FEP film for better fit to the bag contour. Other possible approaches which should be considered are a vacuum form tool or a spray on coating to be applied after bag cure cycle.

The bag penetration panel was fabricated in a manner similar to that for the bag halves. In this case, however, both the 1.27 cm thick flange and the 1.89 cm thick flat mounting surface were laid up using precured inserts of laminated epoxy glass fabric. This procedure allowed a one step layup and cure cycle for the part while allowing reasonably close control of part thickness. Because of the overall thickness of the penetration panel, 6 plys minimum (0.127 cm) at the conical section, only one layer of FEP was bonded (at the inner surface) to the panel. The completed panel is shown in Figure 26.

Figure 26. Purge Bag Penetration Panel

Additional plastic parts fabricated for the purge bag included the support duct (Figure 20) and the instrumentation support fixtures (Figure 27).

3.4 PURGE SYSTEM ASSEMBLY

The manufacturing phase of the program was completed with the assembly of the insulated tank, purge bag, purge and vent hardware and support hardware into an integrated reusable cryogenic propellant storage system. The first step in the assembly was the installation of the tank support strut seal boots. The boots were designed as flexible connections between the purge bag and the support strut. The actual penetration of the fiberglass bag was made using an aluminum cylinder welded to a thin aluminum plate. The aluminum plate was bonded to the inner surface of the bag after locally removing the FEP film. Hysol 934 epoxy base adhesive was used for the installation. Figure 28 shows the boot support tube being bonded in place. Because of the attachment angle for the struts on the existing 2.21 m tank, it was necessary to locally scarf the bag girth flange to accommodate the boot support tube. This accommodation was included in the bag design by establishing the bolt hole locations.

The strut seal boots themselves were made from FEP tubes corrugated for flexibility and etched on the ends for bondability. The boots were purchased as standard parts

Figure 27. Bag Instrumentation Support Fixtures

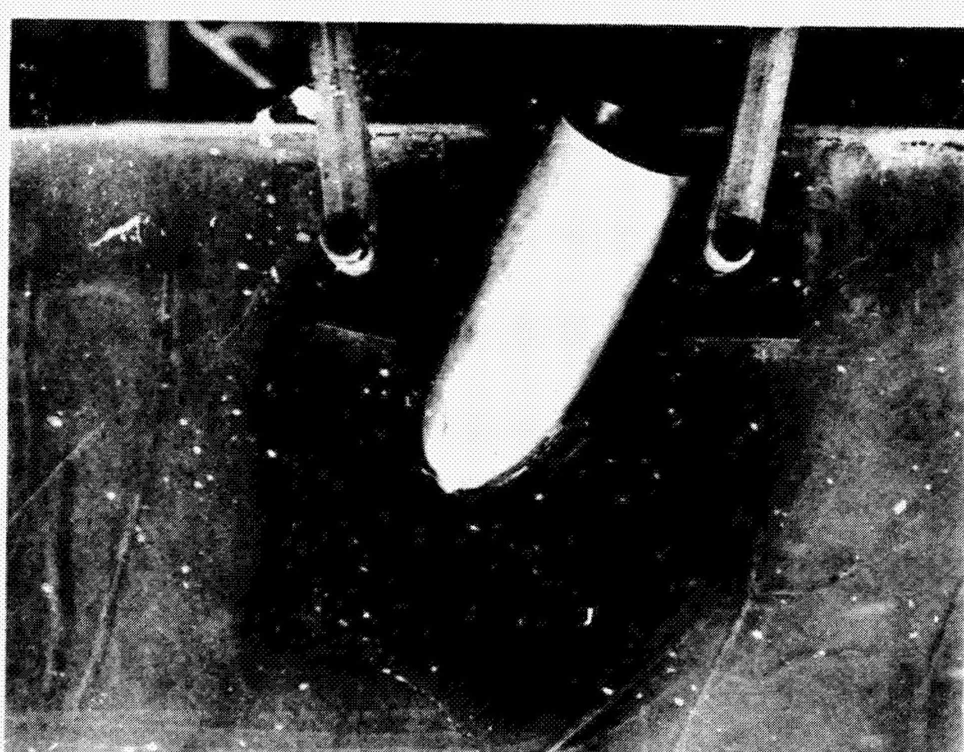

Figure 28. Installation of Tank Strut Seal Boot Support Tube

from Penntube Plastic Company. One end of each boot was bonded to the aluminum support tube while the other end was clamped to a ring on the tank support strut. Figure 29 shows the boots bonded to the support tube, and an insulated fiberglass strut being installed. The strut was sealed against helium gas leakage at the strut ring with FEP tape, Permacel Type P-412 Ribbon Dope Thread Sealant, and clamping the boot to the ring with a band clamp.

Sealing of the purge bag at the mating flanges was accomplished by using bonding techniques rather than special sealing devices such as O-rings. Each bolt hole on the flanges was counter sunk to accept a fiberglass disk which covered the ends of the bolts. The lower flange bolt holes were drilled through, tapped and helical coil inserts installed. Prior to installation of bolts connecting the flanges, a parting agent (Frekote 33) was used to coat the faying surfaces. The bolts were installed, the bolt heads covered with tape and the disks bonded in place using Hysol 934 adhesive. The disk installation was designed to prevent helium leakage along the bolt threads. Sealing at the flange mating surfaces was accomplished with the use of a fiberglass seal strip. The strip was bonded to the edges of the flanges in a continuous 2π radians ring for both girth and penetration flanges. The flange sealing method is shown in Figure 30.

Some difficulty was found in using the flange sealing approach described above. Leakage testing of the completed bag showed that many leaks were present from the surfaces under the bolt sealing disks. It appeared that the surface area on the disks available for bonding to the counter bored flange was insufficient to obtain a perfect leak free bond

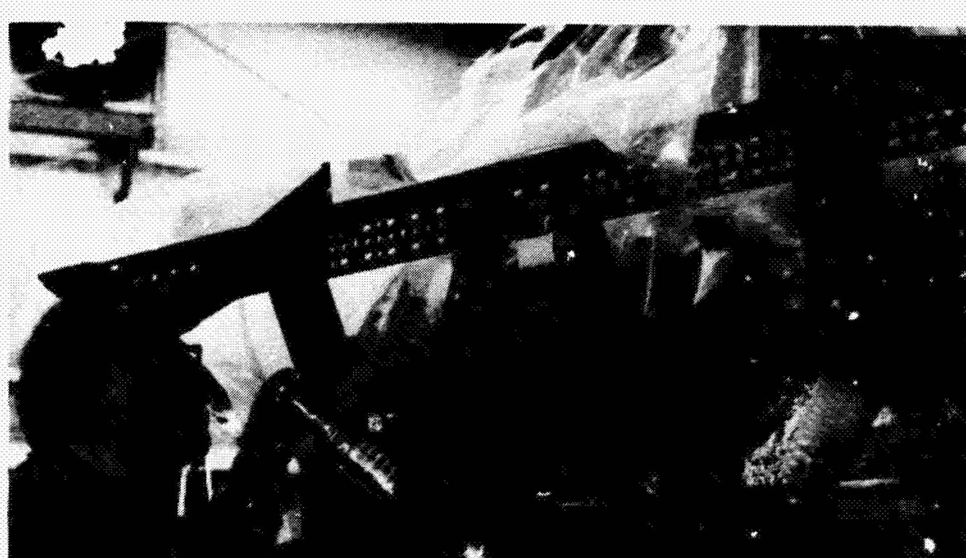

Figure 29. Strut Being Installed in Seal Boot

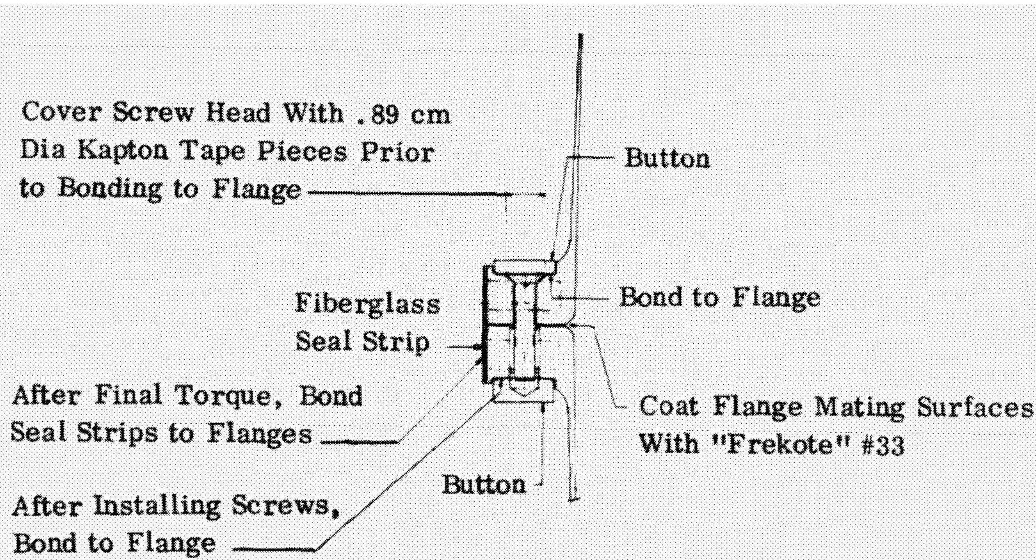

Figure 30. Purge Bag Flange Sealing Technique

on each disk. It was necessary therefore to apply adhesive as a potting compound over the disks to obtain an effective helium gas seal. The seal strips bonded across the exposed edges of the flanges, however, provided a very effective seal against purge gas leakage.

The purge and vent subsystem hardware was selected from existing flight qualified items following an extensive survey of available off-the-shelf hardware (Reference 5). All hardware items for purge and vent subsystems except the vent valve were purchased specifically for use on the performance demonstration test tank. The vent valve was obtained GFE from the Atlas vehicle spares inventory. Table 1 is a list of the major purge and vent hardware items used for the test article. The hardware was mounted to the purge bag penetration panel along with the instrumentation pass-throughs as shown in Figure 31. The 15.24 cm vent valve was mounted to the panel as a final assembly operation to allow all other mechanical connections to be made using the vent port as a "hand hole."

The completely assembled MLI purge and repressurization system test article is shown in Figure 32. All flange seals had been made, support struts attached and purge and vent hardware installed for the performance test program. The test article was subsequently installed in a surrc ıding support shroud and placed in a space simulation chamber for life cycle and performance testing.

Table 1. Major Purge and Vent Hardware for Performance Test Article

Item	Vendor	Part No.	Comments	Qualified Use
Vent Valve	AiResearch	121021	Motor Operated 15.24 cm (6 inch)	Atlas
Gas Supply Valve	Circle Seal	V4076T-2BH	Normally Closed	Similar to Athena Rocket
Relief Valve	Circle Seal	P25-637	MIL-V-8607 and MIL-V-25025	Air Transportable Containers
Bleed Valve	Dyna Sciences	133445-3-7	Motor Actuated	C-123 and F-104 Aircraft
Vent Valve Filter	Western Filter	324117	100 μ Nom., 175 μ Abs.	New
Bleed Valve Filter	Western Filter	324116	100 μ Nom., 175 μ Abs.	New
Pressure Switch	Hydra Electric	12196	0.5-1.5 psig range	C5A Aircraft
Pressure Switch	Hydra Electric	12196-1	1.5-2.5 psig range	C5A Aircraft

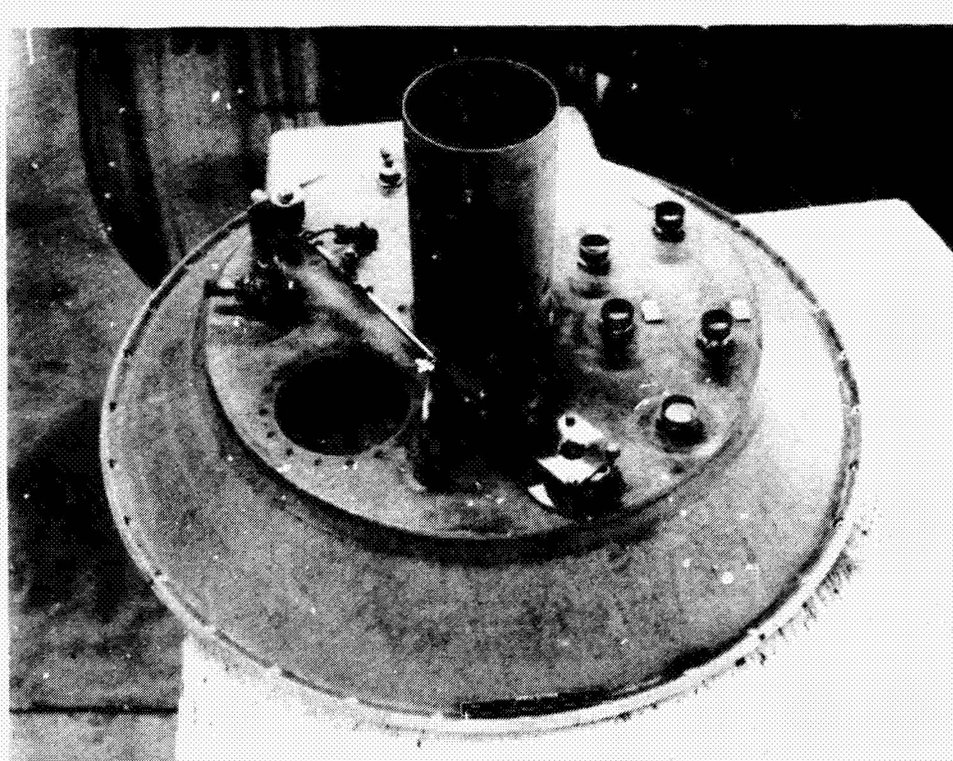

Figure 31. Purge Bag Penetration Panel With Purge and Instrumentation Hardware Attached

Figure 32. Completely Assembled MLI Purge and Repressurization System Test Article

APPENDIX A

This appendix contains the manufacturing plans for fabrication of the plastic portions of the purge bag. The drawings referenced in the plans are the GDCA detailed manufacturing drawings for the purge bag details. The units used for both the manufacturing plans and the manufacturing drawings are English to conform to shop practice at GDCA.

Manufacturing Research and Development Technical Instructions

for Purge Enclosure PD 72-0151 and Enclosure Assembly PD 72-0173

Glass Fabric/Epoxy Laminated Parts

This Manufacturing Research and Development Technical Instructions (MRDTI) establishes the manufacturing procedure for Purge Enclosure PD 72-0151 and for glass fabric/epoxy laminated details on Enclosure Assembly drawing PD 72-0173.

1. Inspection

   1.1 Quality Control shall inspect all points indicated in this MRDTI. Variation from this MRDTI, or drawing requirements shall not be made without written approval by program manager. Such variations shall be noted by Q.C. on the Production Traveler. Formal MRB is not required on this program.

2.	Processing Specifications	GDCA Specification No.
2.1	Glass Fiber Base Reinforced Epoxy Construction for Structural and Electrical Applications	0-75062
2.2	Adhesive Bonding, Potting and Sealing, General Purpose, Process to	0-79129
3.	Materials	
3.1	Epoxy Laminating Materials for use in Glass Reinforced Plastic and Sandwich Construction	0-72009-7
3.2	Tape, Double Coated, Polyester Film	0-06030-001
3.3	Epoxy Compound, 2 Parts Adhesive Bonding, Potting, Sealing and Coating	0-00096-52
3.4	Adhesives, Silicone	0-00090
3.5	Film, Fluorinated Ethylene Propylene	0-00062-1
3.6	Rubber, Silicone, High Temperature Resistant and Low Compression Set	0-00696

4. Tool Preparation - Clean the working surface of all tools with trichloroethylene and apply at least two coats of liquid Frekote 33 or equivalent parting system to the working surfaces. Bake each coat for a minimum of thirty (30) minutes at a tool temperature of 375° F.

5. Fabrication

5.1 Flat laminate fabrication for the following details:

Drawing No.	Dash No.	Description	No. Plies		No. Reqd
PD 72-0151	-7	Splice Strip	2	2 ply × .75 × 4.1	8
	-8	Splice Strip	2	2 ply × .85 × 4.1	4
	-13	Ring Insert }		.25 × OD/Tooling	1
	-14	Ring Insert }		× 95.3 I.D.	1
	-15	Ring Insert		.25 × OD/Tooling × 37.0 I.D.	1
	-16	Splice Ring	2	2 ply × .85 × 4.1	2
	-17	Splice Ring	2	2 ply × .85 × 4.1	4
	-18	Splice Strip	2	2 ply × .85 × 4.1	2
	-19	Splice Strip		2 ply × .85 × 4.1	4
PD 72-0173	-3	Collar Set	62	.62 × 2.10 Dia	4
	-4	Buttons	12	.12 × .550 Dia	137
	-10	Seal Strip	2	2 ply × 1.00 × 103.0	3
	-11	Seal Strip	2	2 ply × 1.00 × 62.0	2

Fabricate on a flat smooth aluminum plate.

5.1.1 Prepare tool surface per Section 3.

5.1.2 Lay up the number of plies necessary to meet drawing requirements for the inserts.

5.1.3 Vacuum bag and cure the laminate to 0-75062 specification.

5.1.4 After cure, cut ring inserts and splice strips to drawing requirements. Sand all surfaces, as necessary and protect from contamination until they are bonded or laminated in place.

5.2 Stiffeners - PD 72-0151-5 and -6 Stiffener Assemblies

5.2.1 Prepare tool surfaces per Section 3.

5.2.2 Layup two plies of 0-73009-7 prepreg on the tool for -9, -10, -22, and -23 stiffeners.

5.2.3 Vacuum bag and cure the laminate per Specification 0-75062.

5.2.4 Sand the faying surfaces of the stiffener details and bond the -9 and -10 stiffeners together. The four segments to form the -5 stiffener assembly may be located on the male bag tool and bonded to form the complete -5 stiffener assembly. Two segments of the -6 stiffeners are similarly bonded to complete the -6 stiffener assembly. Use 0-00096-52 (Hysol E.A. 934) adhesive and bond per 0-79129-4.

5.2.5 Repeat the bonding operation in Section 5.2.4 to bond -22 and -23 stiffeners to make -6 stiffener assemblies.

5.3 PD72-0151-4 Aft Bag

5.3.1 Prepare tool surface per Section 3.

5.3.2 Cut and form barrier film (FEP) to make a tight fitting film over the tool surface. Film splice joints shall be as shown on PD72-0151.

5.3.3 Layup epoxy prepreg (0-73009-7) over the barrier film using care so as not to wrinkle or move the FEP. Layup shall be for specification 0-75062. Reinforcement per Sec E-E Zone E-11, Drawing PD 72-0151, shall be sandwiched between the 2 skin plies.

5.3.4 Position the ring insert segments as shown in the drawing. Identify location to ensure that the bolt hole can be at ℄ of the splice.

5.3.5 After laminating of prepreg has been completed to drawing requirements, apply the other barrier film to the outside surface of the bag using the same procedure as was used for the insider barrier film.

5.3.6 Vacuum bag and cure per 0-75062.

5.3.7 After cure, machine the flange edges to drawing requirements.

5.4 PD 72-0151-3 Aft Bag. Add tool accessory to get forward flange per detail H Zone F-9.

5.4.1 Prepare tool surface per Section 3.

5.4.2 Cut and form barrier film FEP to make a tight fitting film over the tool surface. Film splice joints shall be as shown on PD 72-0151.

5.4.3 Layup epoxy prepreg (0-73009-7) over the barrier film using care so as not to wrinkle or move the FEP. Layup shall be per specification 0-75062.

5.4.4 Position the Ring Insert segments as shown on the drawing. Identify splice location to ensure that bolt hole can be at ℄ of splice.

5.4.5 After laminating of prepreg has been completed to drawing requirements, apply the outer barrier film to the outside surface of the bag using the same procedure as was used for the inside barrier film.

5.4.6 Vacuum bag and cure per 0-75062.

5.4.7 After cure, machine the flange edges to drawing requirements.

5.5 Bag Assemblies - PD 72-0151-1 FWD ASSY and PD 72-0151-2 AFT ASSY.

NOTE: The following operations may be accomplished prior to removing the -4 and -3 bags from the production mold in Sections 5.3 and 5.4.

5.5.1 FWD ASSY. -1: Clean the faying surface and lightly sand the faying surface of the stiffeners.

5.5.2 Position the -3 or the -4 bag on the male tool and position the stiffener(s) on the outside of the bag half.

5.5.3 Mask the area next to the bonding surface of the bag to help position and hold the stiffener in place and secondly, to avoid excess adhesive from bonding to the bag where it is not wanted.

5.5.4 Apply slight continuous pressure to the bond line until the adhesive is cured. Applying vacuum pressure is not required nor is it objectionable.

5.5.5 For -4 Bag Only: Layout for -11 and -2 Boot Fairing cutouts. MAKE SURE TO OBTAIN Q.C. APPROVAL AND SIGN-OFF BEFORE CUTTING.

5.5.6 Cutout penetration parts.

5.5.7 Prepare faying surface inside the bag and the surface of the Boot Fairings for bonding.

5.5.8 Position Boot Fairings and bond in place per 0-79129-4 using 0-00096-52 adhesive (Hysol EA 934).